

**PHOTOVOLTAIC POWERED CHARGING APPARATUS FOR  
IMPLANTED RECHARGEABLE BATTERIES**

**REFERENCE TO PRIOR FILED APPLICATIONS**

**[0001]** This application claims the benefit of U.S. Provisional Application 60/432,116 filed December 10, 2002.

**FIELD OF THE INVENTION**

**[0002]** This invention relates to a rechargeable battery and more particularly to apparatus for recharging an implanted rechargeable battery.

**BACKGROUND OF THE INVENTION**

**[0003]** Implantable medical devices such as speech processors and neurostimulators are typically battery-powered. Although battery technology for such devices continues to deliver ever-longer cell lifetimes, eventually the battery or batteries in an implantable device must be replaced or recharged. Because replacement requires surgical extraction of an implanted medical device, the use of rechargeable ("secondary") batteries is increasingly favored. The battery of an implanted medical device can be recharged transcutaneously, with the device in situ and a battery charger positioned outside of tissue. Inductive charging units are used to recharge implanted batteries. Inductively recharging an implanted device's battery through the skin requires a patient to properly align a charger with respect to the device's recharging circuitry, and keep it there during the recharging period. One such inductance charging unit has a sending (primary) coil powered by a rechargeable cell and incorporates a metal detector to aid in location of a receiving (secondary) coil in an implanted device. The recharging is done daily, and can take up to an hour at a time. This procedure can be inconvenient, uncomfortable, and a source of anxiety for the patient, and requires him to remember to recharge the battery.

**SUMMARY OF THE INVENTION**

**[0004]** Therefore, one object of the invention is to provide comfortable charging of the rechargeable power source of an implanted medical device, by means of an inductive charger, without requiring the patient to monitor the position of the sending coil in relation to the

implanted receiving coil. The rechargeable power source in the implanted device may comprise one or more cells, a capacitor, or a hybrid of the two; for convenience, the word "battery" as used herein may refer to any or all of these.

[0005] Another object of the invention is to provide means to prolong the life of the implanted battery.

[0006] Another object of the invention is to increase the amount of time between required rechargings.

[0007] A battery charger is therefore provided having features selected to meet the above and other objects. The invention includes a photovoltaic powered inductive charging unit mounted to a head covering, such as a cap or hat, for a patient who has an inductively-chargeable device implanted in the skull or brain. Photovoltaic cells provide continuous charging and power for the implanted device when light impinges on the photovoltaic cells. Simply exposing the cap to a natural or artificial light source while wearing it during a portion of each day is sufficient to charge and power the implanted device.

[0008] The battery charger may incorporate a conventional baseball cap. The cap has a sending coil located so that, when the wearer dons the cap, the sending coil lines up with the receiving coil of the implanted device in the patient's skull or brain. A plurality of photovoltaic cells are disposed around the crown of the cap, in order to cover maximum space to maximize efficiency while still maintaining the shape and aesthetics of the baseball cap.

[0009] The battery charger includes a nonphotovoltaic cell, such as a rechargeable battery, which may also be charged by the photovoltaic cells. The nonphotovoltaic cell may be used to charge the implanted device in the absence of sufficient power from the photovoltaic cells. Alternatively, the nonphotovoltaic cell may be a non-rechargeable ("primary") battery. In that case, the primary battery would need to be replaced periodically to ensure sufficient charge.

[0010] The battery charger includes a charge controller to control the source and magnitude of a charging current provided to the sending coil. The charge controller is mounted at the edge of the cap, preferably in proximity to the sending coil. The photovoltaic cells are electrically connected to the charge controller. The nonphotovoltaic cell is also

electrically connected to the charge controller and mounted in the front portion of the cap, preferably on the junction between the crown and the visor. By investing the battery charger with the ability to power the implanted device by the sending coil, the life of the implanted rechargeable battery may be prolonged by reducing the number of charging cycles.

[0011] LED's are mounted on the underside of the visor, remaining just in the peripheral field of normal view, to indicate diagnostic information about the implanted battery. Such information may include whether the battery is in a fully charged state, is being charged, or is completely discharged, which may be indicated by green, yellow, and red, respectively. The LEDs are of a low profile design for easy viewing by the wearer.

[0012] The implanted device includes a rechargeable battery, a battery management system, and a receiving coil.

[0013] The battery management system and charge controller operate cooperatively to direct power to the implanted device by way of the implanted rechargeable battery, the battery in the cap, or the photovoltaic cells on the cap. The charge controller on the cap has the ability to charge the battery from either an external source (AC or DC), or from the photovoltaic cells. The battery management system in the implanted device can provide power from the receiving coil to operate the implanted device while the implanted battery is being charged by the receiving coil.

#### BRIEF DESCRIPTION OF THE FIGURES

[0014] FIG. 1 is a top view of a battery charger.

[0015] FIG. 2 is a side view of the battery charger of FIG. 1.

[0016] FIG. 3 is a block diagram of a photovoltaic powered charging apparatus for implanted rechargeable batteries in combination with a battery powered implantable device.

[0017] FIGS. 4-11 are block diagrams showing various modes of operation of the apparatus of FIG. 3.

## DETAILED DESCRIPTION

[0018] The following text describes a preferred mode presently contemplated for carrying out the invention and is not intended to describe all possible modifications and variations consistent with the spirit and purpose of the invention. The scope of the invention should be determined with reference to the claims.

[0019] FIG. 1 is a top view of an example of a battery-charging apparatus 10, wherein the device is based on a conventional baseball cap. A photovoltaic powered inductance charging unit 11 is mounted to the cap 13 for a patient who has an inductance charged, battery-powered device (indicated by reference numeral 30 in FIG. 2) implanted in the skull or brain. Charging unit 11 comprises a plurality of photovoltaic cells 14 mounted on the crown 20 and visor 24 of cap 13, a sending coil 12 (see FIG. 2) mounted at the edge of cap 13, and a charge controller 18 mounted to the cap 13, preferably in proximity to the sending coil 12. The photovoltaic cells 14 allow continuous charging and power for the implanted device when light impinges on them, and cover maximum space on the cap to maximize efficiency, while still maintaining the shape and aesthetics of the baseball cap.

[0020] The cap 13 also includes a nonphotovoltaic cell 16, mounted in the front portion of the cap 13, preferably on the junction between the edge of the crown 20 and the visor 24. Nonphotovoltaic cell 16 may be a rechargeable cell, such as model 18650 Li-ion Cell available from Quallion LLC, which is also charged by the photovoltaic cells 14. Nonphotovoltaic cell 16 is used to charge the implanted device in the absence of sufficient power from the photovoltaic cells 14. Alternatively, the nonphotovoltaic cell 16 may be a primary cell, which would need to be replaced periodically to ensure sufficient charge.

[0021] Charge controller 18 controls the charging current source and magnitude. That is to say, the charge controller 18 selects either the photovoltaic cells 14, the nonphotovoltaic cell 16, or some other source (described below) as the source of charging current provided to the sending coil 12, and also controls the magnitude of the charging current. The photovoltaic cells 14 are electrically connected to charge controller 18. The nonphotovoltaic cell 16 is also electrically connected to charge controller 18.

[0022] As shown in FIG. 2, LED's 26 are mounted on the underside of the visor, remaining just in the peripheral field of normal view, to indicate diagnostic information about the implanted battery. Such information may include whether the battery is in a fully charged

state, is being charged, or is completely discharged, which may be indicated by green, yellow, and red, respectively. The LEDs are of a low profile design intended to be easily viewable by the wearer.

[0023] The cap 13 has a sending coil 12 mounted on a downwardly-extending tab 27 formed as part of or attached to the hat's band. The tab 27 is located so that when the wearer dons the cap in the conventional manner, the sending coil 12 lines up with the receiving coil 22 for charging the implanted battery 24 of the implanted device 30 in the patient's head 28, or for powering the device, or both. This same pair of coils 12 and 22 may be used for other communication between the charger and the implanted battery, as is known in the art. Alternatively, a second pair of primary and secondary coils (not illustrated) may be provided for communication without having to provide a complex algorithm to accommodate both functions on the same pair of coils.

[0024] A block diagram of a photovoltaic powered charging apparatus for implanted rechargeable batteries in combination with a battery-powered implanted device is shown in FIG. 3. The photovoltaic powered charging apparatus includes elements described above which are mounted to the cap 13. In this regard, the sending coil 12, the photovoltaic cell array 14, the nonphotovoltaic cell 16, and an external power source 34 are electrically connected to the charge controller 18. In the battery-powered implanted device, the receiving coil 22, a battery 24, and circuitry, sensors, and actuators (not shown) of the implanted device 30, are electrically connected to the battery management system 32. Note that the elements 22, 24, 30, and 32 are shown separately. This is for purposes of illustration only as one, some or all of elements 22, 24, and 32 may be integrated into and enclosed in the implantable device 30. In addition, the sending coil 12 is shown aligned with the receiving coil 22 as is desirable to maximize the power coupled or transmitted transcutaneously from the sending to the receiving coil.

[0025] As shown in FIG. 3, the battery management system 32, located within the implanted device 30 or within the battery 24 thereof, controls whether the device 30 is powered by the implanted battery or by the inductance coils 12 and 22, based on the level of charge of the battery, the power demand from the device, and the power supplied by the charging coil.

[0026] The battery management system 32 and charge controller 18 have the ability to operate cooperatively to direct power to the implanted device 30 by way of the implanted rechargeable battery 24, the nonphotovoltaic cell 16 in the cap, or the photovoltaic cells 14. The charge controller 18 on the cap has the ability to recharge the nonphotovoltaic cell 16 with power obtained from either the external source 34 (AC or DC), or from the photovoltaic cells 14. The battery management system 32 in the implanted device can direct power from the secondary coil 22 to the implanted device 30 while the secondary coil 22 is charging the implanted battery 24. In this way, the battery management system 32 can optimize the charging algorithm and charge state of the implanted battery 24. For example, the battery management system may allow the battery to drain somewhat if it is better for the battery to not remain constantly fully charged. The charge controller and battery management system work together to choose the optimal power source for the implanted medical device and conserve the implanted rechargeable battery.

[0027] FIGs. 4-11 are block diagrams showing various modes of operation of the rechargeable power source and the battery powered implanted device. In FIG. 4 (Mode 1), the implanted battery 24 is charged from the photovoltaic cell array 14. In FIG. 5 (Mode 2), the implanted battery 24 is charged from the external (nonphotovoltaic) cell 16. In FIG. 6 (Mode 3), the implanted battery 24 is charged from an external DC power source 34. In FIG. 7 (Mode 4), the external (nonphotovoltaic) cell 16 is charged by the photovoltaic cell array 14. In FIG. 8 (Mode 5), the LED array 26 is used to communicate the condition of the implanted battery 24. In FIG. 9 (Mode 6), the implanted device 30 is run from the photovoltaic array 14 via the sending coil 12 and the receiving coil 22. In this mode, neither the external storage cell 16 nor the implanted battery 24 is drained. In FIG. 10 (Mode 7), the implanted device 30 is run from the external (nonphotovoltaic) cell 16. In this mode, the implanted battery 24 is not used to power the device 30. In FIG. 11 (Mode 8), the implanted device 30 is run from an external DC power source 34. In this mode, neither the external storage cell 16 nor the implanted battery 24 is drained, and light is not required because the photovoltaic cell array 14 is not used.

[0028] While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention set forth in the claims. Furthermore, various aspects of the invention may be used in other

applications than those for which they were specifically described herein. For example, a battery-charging cap may be used to recharge a nonimplanted medical device, such as a hearing aid worn behind the ear; in that case, the recharging may be inductive or direct coupled. Other devices that may be recharged by the cap of the present invention include, but are not limited to, fully implantable speech processor, cochlear implant, deep brain stimulator, and fully implantable middle ossicular stimulator.